Effects of Yttrium on Mechanical Properties and Microstructures of Ti-Si Eutectic Alloy

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Abstract: The effects of rare earth (Y) on Ti-Ti_5Si_3 eutectic alloy are studied. The results of microstructure analysis show that the colonies and microstructures of the raw alloy are transformed evidently with the addition of Y. With proper addition of yttrium (0.025at%), the shape and size of the coarse Ti_5Si_3 phases of the colonies change to be fine and round meanwhile the microstructure of the alloy goes into uniformity. The compressive ductility and strength at room temperature are also improved. The effects of yttrium on the alloy are likely due to that Si atoms in Ti_5Si_3 phase are partially substituted for yttrium atoms which results in silicide $Ti_5(Si, Y)_3$ phases.

Key words: Ti-Si alloy; micro-alloying; yttrium; mechanical property; microstructure

钇对 **Ti-Ti_5Si_3** 共晶合金微观组织和力学性能的影响. 吴鹤, 韩雅芳, 陈熙琛. 中国航空学报(英文版), 2005, 18(2): 171-174.

摘 要: 研究了稀土元素钇(Y)对 Ti-Ti_5Si_3 共晶合金的微合金化作用。微观组织分析表明, 添加微量 Y, 可以改变原始钛硅合金的共晶团形态和组织形貌。适量 Y 的加入(原子比 0.025%), 不仅使共晶团中粗大的 Ti_5Si_3 相颗粒明显细化和钝化, 而且合金的微观组织也更加均匀。合金的室温压缩塑性和强度也得到了有效提高。稀土元素 Y 对钛硅合金的作用, 很可能是因为 Y 原子替代了 Ti_5Si_3 相中的部分 Si 原子, 形成硅化物 $Ti_5(Si, Y)_3$ 所致。

关键词: 钛硅合金; 微合金化; 钇; 力学性能; 微观组织

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Ti-Si eutectic alloy is a new kind of as-cast titanium alloys, whose strengthen mechanism is different from that of the traditional titanium alloys. The Ti-Si alloy system is strengthened by brittle phases (intermetallics Ti_5Si_3) and composed of tough Ti as matrix, which is similar to the famous typical eutectic alloys such as Fe-C alloy and Al-Si alloy. Also, the problem of Ti-Si alloys is the low ductility at RT (room temperature), which is the key technology in the research and application. It is showed that the brittleness of Ti-Si alloy is due to the original brittleness of intermetallics Ti_5Si_3, whose effect on the mechanical properties of the alloy is related with the shape and size of the Ti_5Si_3 phases in the microstructure[1]. Thus, it's important to improve the ductility of Ti-Si alloy at RT for application.

Micro-alloying is a common way to improve the strength and ductility of eutectic alloys. The solidification behaviors and microstructures of the alloys are reformed by the minim elements so that the mechanical properties can be improved. Magnesium, alkaline earth and rare earth elements are very important to resolve the problem in technologies because of their characters, especially the high chemical activity. The solubility in the titanium of these elements is very low so that their effects generally are minimize and strengthen the grains of the pure metal or solid solution matrix. Sala found that the ductility at RT of Ti-6.5wt% Si hypo-eutectic alloy can be improved with micro-alloying of bismuth[2,3]. In this present paper, the effect of minim yttrium on the mechanical properties and microstructures of Ti-8.5wt% Si eutectic alloy are

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discussed.

1 Experimental Procedure

The Ti-Si alloys are prepared by arc-melting with non-consumable tungsten electrode in a water-cooling copper hearth under a purified argon atmosphere. The raw materials used in this study are sponge titanium with the purity of 99.5% and single crystal silicon. Before the ingots are melted, sponge titanium is melted as getter. Each ingot are melted for five times to ensure uniform composition of the alloy. The weight of each ingot is about 20 gram to ensure that the alloy is melted completely. Then, the ingots are cast as small rod-shaped samples approximately 8 mm in diameter by vacuum suction.

The sizes of compressive samples are about Ø7 mm × 11 mm. The ratio of length to diameter (L/D) is about 1.57, which is suitable for studying the strength and ductility of brittle materials. The compressive tests are conducted by using an Instron Universal Testing Machine at a speed of 2 mm/min. Three samples are tested in each condition to evaluate the compressive properties. Metallographic specimens are prepared from the rod samples. The samples are polished by using MgO powder and etched with dilute aqueous solution containing 1-3 ml/l HF and 2-6 ml/l HNO_3 (Kroll reagent[4]). In a scanning electronic microscope (JSM-5600HV/LV), study of microstructures and fracture morphologies is carried out and the distributions of yttrium in matrix and Ti_5Si_3 phases are analyzed by X-ray energy dispersive spectroscopy (X-EDS).

2 Results and Discussions

2.1 Mechanical properties

The experimental results of compressive properties at RT of eutectic Ti-8.5wt%Si alloy are σ= 1226 MPa and ε = 2.4%[5]. The compressive properties of Ti-8.5wt%Si alloy with different additions of yttrium are shown as Fig. 1. It is indicated that not only the strength but also the ductility of the alloy reaches to the maximum with addition of 0.025at% yttrium. Thereinto, the rises in strength and ductility are 15% (σ= 1411 MPa) and 2 times (ε= 7.1%) respectively. Both of the strength and the ductility decrease with more addition of yttrium. The compressive properties of Ti-8.5wt% Si alloy with addition of exceeding 0.5at% yttrium are nearly equal to that of no addition.

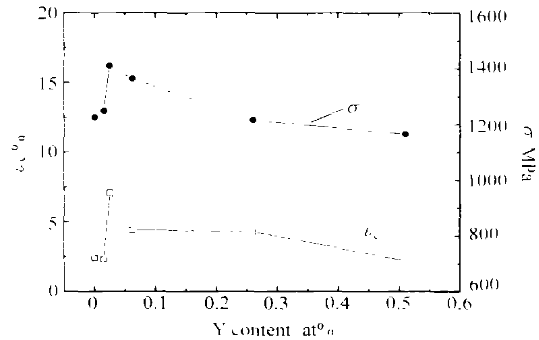
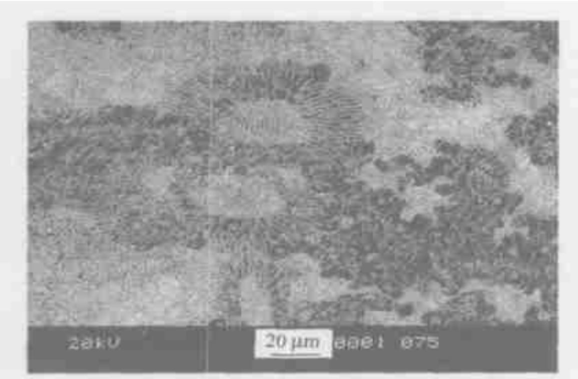


Fig. 1 Effects of minim yttrium on compressive properties of Ti-Si eutectic alloy

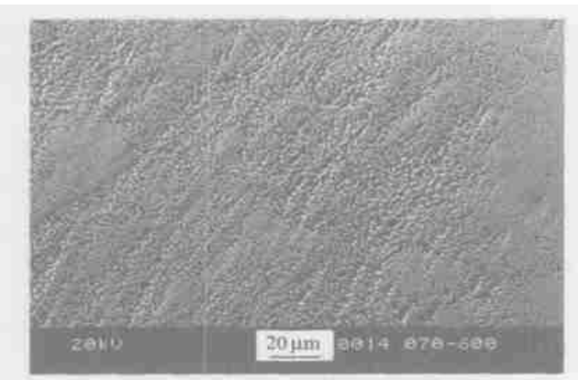
2.2 Microstructures

The microstructures of Ti-8.5wt% Si alloy with different additions of yttrium are shown as Fig. 2. In Fig. 2, the dark matrix phase is α-Ti and the grey precipitation phase is Ti_5Si_3 grains. With suitable addition of yttrium, the chrysanthemum shape of eutectic colony in the microstructure of Ti-8.5wt% Si alloy are increase in quantity and decrease in size. Comparing with the microstructure of Ti-8.5wt% Si alloy with no addition (as Fig. 2(a)), the diameter of eutectic colony in alloy with 0.025at% addition of yttrium decreases from 70 μm to 20 μm and the size of Ti_5Si_3 grains in the center of eutectic colony decreases from above 1 μm to less than 0.2 μm (as Fig. 2(b)). Also, the dimensions of Ti_5Si_3 particles among the eutectic colony decreases from 5-8 μm to below 1 μm. The finer grains certainly resultes in the improvement on mechanical properties of alloy.

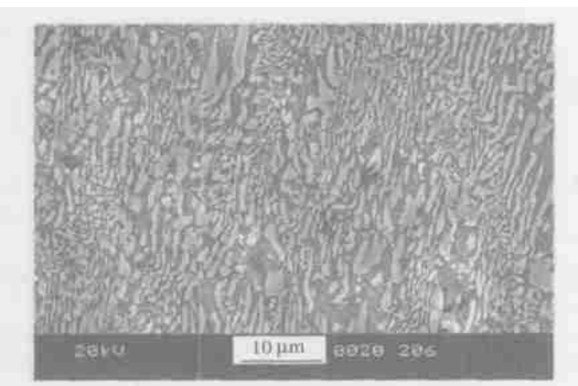
It is found that the properties of Ti-8.5wt%Si alloy decreases when the atom ratio of yttrium is beyond 0.5at%, which is tied up with the microstructure. The microstructures of Ti-8.5wt%Si



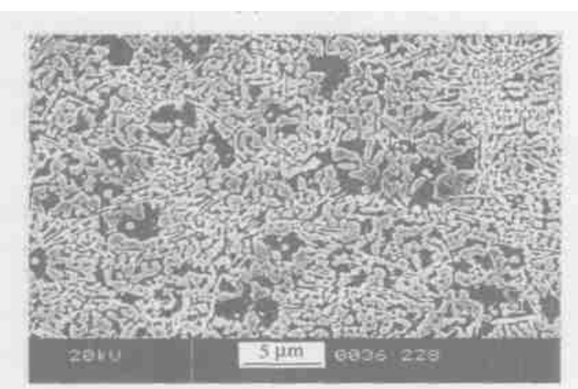
(a) 0%



(b) 0.025at%



(c) 0.26at%



(d) 2.5at%

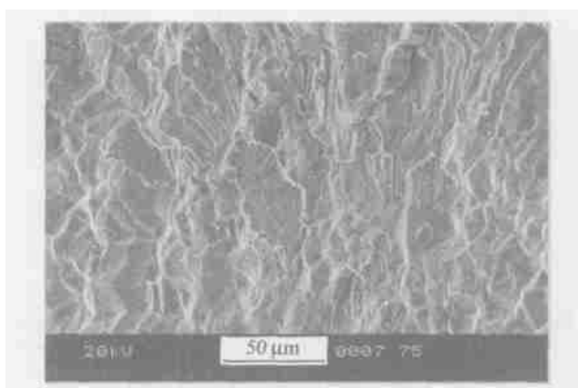
the black phase is Ti matrix; the grey phase is Ti_5Si_3

Fig. 2 Microstructures of Ti-Si eutectic alloy modified by yttrium

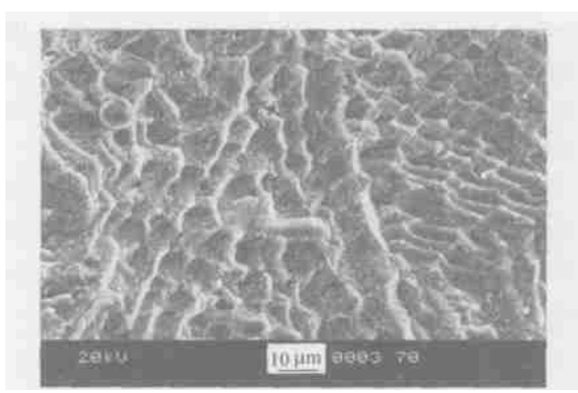
alloy with addition of 0.26at% and 2.5at% yttrium are shown respectively as Fig. 2(c) and Fig. 2(d). It is exhibited that not only the figures of Ti_5Si_3 phases go into abnormity and coarse and acuity but also the microstructures get uniform with the increasing addition of yttrium. The character of the microstructures results in the decrease of the mechanical properties of alloy.

2.3 Fracture mechanisms

The contrast of compressive fracture morphologies of Ti-8.5wt% Si alloy is shown as Fig. 3. It is observed that the fracture mechanism of alloy with addition of 0.025at% yttrium is similar to that with no addition, which is identified of the tiny ductility distortion of matrix (α-Ti phases) and brittle cleavage of second phases (Ti_5Si_3 phases). Therefore, the improvement on ductility at RT of Ti-Si alloy is restricted although the ductility can be improved notably with proper amount addition of yttrium because the fracture mechanism do not change.



(a) no addition

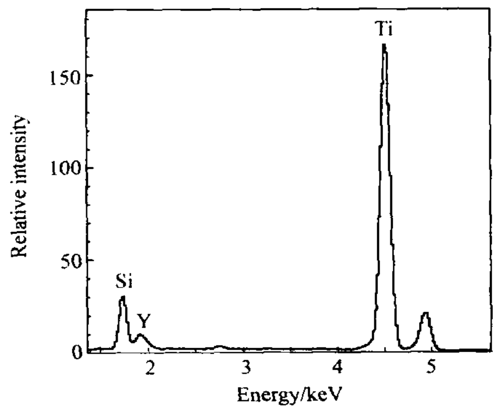


(b) 0.025at% yttrium

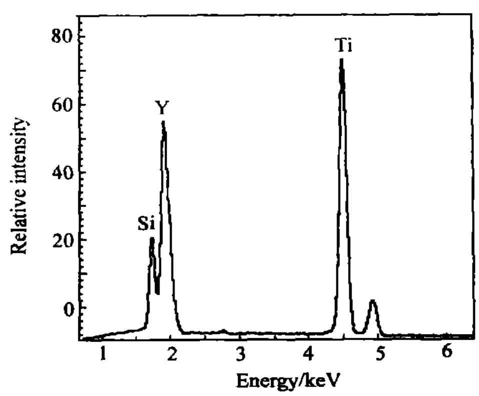
Fig. 3 Fracture morphologies of Ti-Si eutectic alloy

2.4 Distributions of RE(Y) in the matrix and phases

The X-EDS analysis of distribution of yttrium in α-Ti matrix and silicide phase of Ti-8.5wt% Si eutectic alloy with addition of 2.5at% yttrium are shown as Fig. 4. The results indicates that the ratio of yttrium content in Ti_5Si_3 phase and α-Ti matrix is about 10∶1. It is shown that yttrium on the eutectic alloy strongly affects the Ti_5Si_3 phases in fact. The X-EDS results of the content of each element in the silicide of the alloy are Ti (59.83%), Si (11.19%) and Y (28.98%). The form of silicide can be nearly expressed as $Ti_5(Si, Y)_3$. Possibly the Si atoms in the new silicide $Ti_5(Si, Y)_3$ are partially substituted for yttrium atoms.



(a) α-Ti



(b) Ti_5Si_3

Fig.4 Distributions of yttrium in α-Ti and Ti_5Si_3 phase of Ti-Si eutectic alloy

3 Conclusions

(1) The compressive ductility of Ti-8.5wt% Si eutectic alloy can be improved notably by micro-alloying of proper amount of yttrium. With 0.025at% addition of yttrium, the ductility reaches 7.1% which increases by 2 times as compared with as-cast alloy.

(2) The microstructures of Ti-8.5wt% Si eutectic alloy can be clearly changed with minim addition of yttrium. The improvement of ductility with proper amount of yttrium is related to the amount of eutectic colony and the size of Ti_5Si_3 phase in the microstructure of alloy.

(3) Most atoms of yttrium addition exists in the silicide phases. That the Si atoms in the Ti_5Si_3 phase are partially substituted for yttrium atoms results in silicide $Ti_5(Si, Y)_3$ phases.

References

[1] Zhang L, Flower H M. Composition and lattice parameters of sillicide and matrix in cast Ti-Si-Al-Zr alloy [J]. Mater Sci Technol, 1991, 7(9): 812-817.

[2] Saha R L, Nandy T K, Misra R D K, *et al*. Microstructural changes induced by ternary additions in a hypo-eutectic Ti-Si alloy[J]. J of Mat Sci, 1991, 26(10): 2637-2644.

[3] Saha R L, Nandy T K, Misra R D K. On the effect of bismuth in a cast Ti-Si eutectic alloy[J]. Scri Metal, 1989, 23(1): 81-86.

[4] 王金友, 葛志明, 周彦邦. 航空用钛合金[M]. 上海: 上海科学技术出版社, 1985. 291-292.
Wang J Y, Ge Z M, Zhou Y B. Titanium applications on aeronautics[M]. Shanghai: Shanghai Publishing House of Science Technology, 1985. 291-292. (in Chinese)

[5] 吴鹤. 钛硅共晶合金基础研究[D]. 北京: 北京航空材料研究院, 2002.
Wu H. Basic research on Ti-Si eutectic alloy[D]. Beijing: Beijing Institute of Aeronautical Materials, 2002. (in Chinese)

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